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Performance of *terminalia superba* and *triplochiton scleroxylon* seedlings under different forest canopy

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Abstract
This paper presents the performance of *Terminalia superba* and *Triplochiton scleroxylon* seedlings in enrichment planting in different forest canopy types or disturbance types (Skid trail, landing bay and undisturbed area). An area of 0.05ha (50m x 10m) plot each was purposively selected and demarcated in landing bay, skid trails and undisturbed area in Asenanyo Forest Reserve in the Nkawie Forest District. Complete Randomized Design (CRD) was used to lay different 50m x 10m plots in each disturbance area. There were five replicates each of *Terminalia superba* and *Triplochiton scleroxylon* seedlings planted at 6m by 6m planting distance in each canopy type. Soil samples were randomly collected at each of the three different forest disturbance sites at a depth of 0–20 cm. The results revealed a 100% survival of *Triplochiton scleroxylon* whereas that of *Terminalia superba* was 33%. The mean diameter for *Terminalia superba* seedlings across the three different forest gap types was 0.59±0.25cm whereas *Triplochiton scleroxylon* seedlings recorded 0.91±0.48cm. The height of *Terminalia superba* seedlings was 42.60±9.43cm whiles *Triplochiton scleroxylon* seedlings was 71.20±26.67cm. The plant condition score across the different canopy types range from 0-5 for *Terminalia superba* and 2-5 for *Triplochiton scleroxylon*. The number of leaves ranged from 0-14 for *Terminalia superba* and 5-15 for *Triplochiton scleroxylon*. The soil bulk density of the skid trail was significantly ($p<0.05$) increased by 25.8% whereas the landing bay soil bulk density was significantly ($p<0.05$) increased by 59.2% compared to the control. The soil porosity of the skid trail soil significantly ($p<0.05$) reduced by 12.5% but the landing bay soil porosity significantly ($p<0.05$) reduced by 45.3% relative to the control. The skid trail forest disturbance soil had the moisture content increased by 0.30% whereas the landing bay soil moisture content decreased by 63.2% compared to the control. Generally, the growth performance of *Terminalia scleroxylon* seedlings in the three selected gap types was better than *Terminalia superba*.

Keywords
Enrichment planting — Forest canopy gaps – Skid trail — Landing bay — Survival survey

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Contents

Introduction

In much of the history of human civilization, forests have played key roles in global, national and local economies, especially in shaping the socio-cultural life of people and quality of the environment. In Ghana, forests provide goods such as timber and other non-timber products (e.g. bamboo, chew stick, game) which help most communities to meet the requirements for rural economy. The forest supports the livelihood of about 20 million inhabitants particularly in rural communities. Though, the forests are essential due to the wide variety of goods and services they provide, they are under threat from especially human-induced disturbances[1-2]

The 2010 Global Forests Resources Assessment showed that there was a 2% (135, 000 ha) loss of forest annually from 1990-2000 in Ghana[3] Moreover, most of the country's forest resources are considered to be degraded. Most of the indigenous species like, Milicia excels and Milicia regia, the mahoganies (Khaya and Entandrophragma species), Pericopsis

elata, Nauclea diderrichii, and *Triplochiton scleroxylon* which, mainly generate substantial revenues for Ghana's economy; have been drastically reduced over the past decades due to unsustainable agriculture, conversion to agriculture, wanton logging, wildfires, firewood collection and charcoal production, mining, population pressure, poorly defined land and resource tenure and external factors including market failures, international trade, and the imposition of economic programs such as the Structural Adjustment Program[4]. However, studies have shown that these indigenous species can be restored through enrichment planting [5]. Enrichment planting is mostly carried out either for commercial or silvicultural purposes [6].

In the case of Ghana, the former was why it was considered. This management technique which was done through line planting was used in the 1940s and 1950s mainly in the Wet evergreen forest zone to improve the stocking of commercially valuable species [5]. Though enrichment planting approach has reportedly been successful in some secondary forests in the Amazon areas [7][8], however, it failed in Ghana [9]. The failure was due to unfavorable results from practices such as canopy manipulation and competition from weeds[10]. There is paucity of information to improve enrichment planting and reforestation of degraded forest reserves in Ghana . So it is a nerve-racking issue to study the performance of *Terminalia superba* and *Triplochiton scleroxylon* in skid trail, landing bay and undisturbed forest soil in Asenanyo Forest Reserve priority enrichment planting project.

The study is aimed at investigating the performance of *Terminalia superba* and *Triplochiton scleroxylon* seedlings in enrichment planting across different forest disturbance types. This approach would help select tree species appropriate for enrichment planting in the reserve. The specific objective of the study include: (a) to find out percent survival of *Terminalia superba* and *Triplochiton scleroxylon* seedlings under different soil disturbance types (b) to find out growth performance of *Terminalia superba* and *Triplochiton scleroxylon* seedlings under different soil disturbance types (c) to compare soil bulk density, porosity, moisture content, and organic matter content of the different disturbed areas and relate it to growth performance of the two timber species.

1. Materials and Methods

1.1 Study area

The Asenanyo Forest Reserve lies between latitude $6^o17'$ and $6^o36'$ north and longitudes $1^o50'$ and $2^o16'$west. The reserve is a continuous block which is only divided into two unequal halves by the Kumasi- Bibian Road and is situated about 70km from Kumasi. The gross area of the Asenanyo Forest Reserve is 22,792 hectares. The land is undulating over the greater part of the Reserve with an average height of 152-198m above sea level. The reserve lies in two-peak rainfall belts, with the maximum during May-June and the minimum during September –October. The Asenanyo River Forest Reserve lies in the 1250-1500mm isohyets zone [13]. Annual rainfall range from 2005-2009 periods is 1,051-1,522mm according to Bibiani

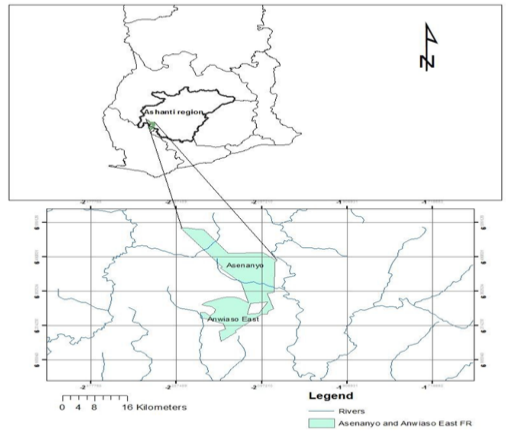

Figure 1. Asenanyo River Forest Reserve

meteorological station. The mean monthly temperature of the area for the period 2005-2009 is 27.9 ^{o}C. The mean annual relative humidity recorded is about 84%. There are four main soil associations within the reserve as follows: - The Bekwai-Domenasi-Oda complex consisting of red clay loams covering 68% of the reserve on gentle undulating terrain. The Kumasi-Domenasi-Offin complex is less extensive and occurs mainly on the gentle hills and slopes, soils in this association are usually gritty red loams. The Kobeda-Mim-Oda complex is confined to the Sumtwitwi Range and consists of soils which are skeletal in nature. The Birim-Chich where compound is usually associated with recent or old alluvia. It covers small areas on river terraces and flood plains and is relatively rare [11]. The Asenanyo reserve was classified as belonging to the Celtis- *Triplochiton* association [12], and lies within Moist Semi-deciduous North-West subtype (MSNW)[13]. The area of the Asenanyo Forest Reserve to the north of the Asenanyo River however, falls into the South-East subtype (MSSE) of this zone [14]. Floristically, the area is rich containing 335 species. Forest tree families commonly occurring in the reserve include: *Moraceae*, *Sterculiaceae*, *Ulmaceae*, *Rubiaaceae*, *Bombaceae* and *Combraceae*. Generally, floristic diversity and life-form categories in the reserve include large trees capable of exceeding 30m in height (megaphanerophyte), small trees, large climbers, small understorey climber, shrubs, herbs, pteridophytes and epiphytes. Table 1 shows the description of the scores on the state of the planted seedlings during the assessment.

Table 1. Description of the score on the state of the planted seedlings during assessment

Ranking Scale	Description of seedlings Condition
0	Dead
1	No leaf but not dead
2	"With leaves but warped, wrinkled and brownish coloration
3	"With leaves, no warping, no wrinkles, but showing brownish coloration
4	Healthy green leaves but 30% reduction in number of leaves
5	Full complement of green healthy leaves

1.2 Experimental design and Data collection

An area of 0.05ha (50m × 10m) plot each was purposively selected and demarcated inlanding bay, skid trails and undisturbed area in the reserve. Two different 50m × 10m plots were laid in each disturbance area. Complete Randomized Design (CRD) was used in this experiment. *Terminalia superba* and *Triplochiton scleroxylon* were the experimental materials selected for the enrichment planting experimental trial. There were five replicates each of *Terminalia superba* and *Triplochiton scleroxylon* seedlings planted at 6m by 6m planting distance in the three different forest disturbance types. The response variables in this research were: the mean diameter of seedlings, seedlings stumps height, number of leaves and description of seedling conditions. Soil samples were randomly collected from the three different forest disturbance sites with soil auger at 0–20cm depths. There were 10 replicates of soil samples from each plot (50m × 10m) for bulk density, moisture content, porosity and percentage organic matter content determination across the three different disturbance types.

One-way ANOVA was conducted to compare mean diameter, mean height, and mean number of leaves of *Terminalia superba* and *Triplochiton scleroxylon* plant seedlings across the three different soil disturbance types at α= 5% level of significance. Soil porosity, bulk density, moisture content, percentage organic matter content were also compared across the different canopy and soil disturbance types at α= 5% level of significance. Fisher's LSD multiple comparisons tests was performed in situations where there was significant difference among the three different soil disturbance types.

2. Results

2.1 Effect of different forest soil disturbance types on seedling diameter, number of leaves, seedling condition and seedling height growth of *Terminalia superba*

From table 2, the *Terminalia superba* seedlings under skid trail canopy had seedling conditionof 1.60±2.07 (i.e. with leaves but warped, wrinkled and showing brownish coloration), landing bay was 0.40±0.55 (i.e. no leaf but not dead) and the mean rank in the undisturbed forest canopy was zero (i.e. dead) during the survival survey (table 2). There was no significant difference (p> 0.05) in the condition of *Terminalia superba* seedlings under the different forest soil disturbance types. In comparing the three canopy types, the skid trail canopy showed the highest number of leaves with an average of 3.40±5.98 compared to the landing bay forest canopy, which had 1.2±1.79 leaves on average. All the *Terminalia superba* seedlings under the undisturbed forest canopy were dead. There was no significant differences in the number of leaves across the three different forest soil disturbance types, p>0.05.

The diameter of *Terminalia superba* seedlings in the skid trail forest canopy was 0.60±0.22cm, undisturbed forest canopy was 0.60±0.22cm and landing bay was 0.58±0.35cm. No significant differences (p>0.05) was found among the diameter growth across the treatments. The undisturbed forest canopy showed the highest height growth of *Terminalia superba* seedlings with an average of 48.60±5.13cm followed by landing bay, 41.80±8.79cm and the least mean height recorded is 37.40±11.33cm in the skid trail soil. But no significant differences was found among the average height growth performance across the treatments, p>0.05.

Table 2. One-way ANOVA of sapling condition, number of leaves, seedlings diameter, seedling height and percent survival of *Terminalia superba* under three different forest soil disturbance types and forest canopy types in Asenanyo Forest Reserve

Terminalia superba

Treatment		Average rank of seedling condition	Number of leaves	Seedling diameter (cm)	Seedling height (cm)
Skid trail	Mean	1.60±2.07	3.40±5.98	0.60±0.22	37.40±11.33
	Range	0.00-5.00	0.00- 14.00	0.50-1.00	25.00-52.00
Undisturbed forest	Mean	0.00	0.00	0.60±0.22	48.60±5.13
	Range	0.00	0.00	0.50-1.00	45.00-57.00
Landing bay	Mean	0.40±0.55	1.20±1.79	0.58±0.35	41.80±8.79
	Range	0.00-1.00	0.00-4.00	0.08-1.00	30.00-50.00
Total	Mean	0.67±1.35	1.53±3.64	0.59±0.25	42.60±9.43
	Range	0.00-5.00	0.00-14.00	0.08-1.00	25.00-57.00
P-value		0.40±0.55	1.20±1.79	0.58±0.35	41.80±8.79

Values with similar letter (s) within a column are not significantly different at α=5% (0.05) by Fisher's LSD multiple comparison tests.

2.2 Effect of different soil disturbance types on seedling diameter, number of leaves, seedling condition and seedling height growth of *Triplochiton scleroxylon*

Table 3 shows the observations that were made on *Triplochiton scleroxylon* seedlings under the different forest soil disturbance types studied. The highest plant condition rank of 4.40± 0.89 was recorded for skid trails, followed by undisturbed forest, 3.80±0.45 and the least was recorded in the landing bay forest canopy as 3.00±0.7. There was significant differences across the treatments at $p<0.05$, $p=0.027$. Fisher's LSD multiple comparisons test showed that *Triplochiton scleroxylon* seedlings under the skid trail canopy were significantly better than seedlings in the landing bay, $p<0.05$.

However, the skid trail seedlings condition were not significantly better ($p> 0.05$) than the condition of seedlings under the undisturbed canopy. *Triplochiton scleroxylon* seedlings under the undisturbed forest canopy showed the highest number of leaves of 10.20±1.48 followed by the landing bay canopy with, 8.2±2.49 and the skid trail canopy, 8.0±4.06. There was no significant differences in the number of leaves across the different canopy types, $p>0.05$.The diameter of *Triplochiton scleroxylon* seedlings in the skid trail was 0.84±0.48cm, undisturbed was 0.84±0.48cm and landing bay was 1.06±0.56cm. However, no significant differences was found among the diameter growth across the different forest soil disturbance types, $p>0.05$. The landing bay forest canopy showed the least height growth of *Triplochiton scleroxylon* seedlings of 69.60±31.26cm. The mean height growth under skid trail canopy was 72.00±27.46cm and undisturbed forest canopy was 72.00± 27.46cm. However, no significant differences $p<0.05$ was found among the height growth under different forest soil disturbance types, $p>0.05$.

Table 3. One-way ANOVA of seedling condition, number of leaves, seedling diameter, seedling height and percent survival of *Triplochiton scleroxylon* under three different soil disturbance types and forest canopy types in Asenanyo Forest Reserve

{Triplochiton} {scleroxylon}

Treatment		Average rank of seedling condition	Number of leaves	Seedling diameter (cm)	Seedling height(cm)
Skid trail	Mean	4.40±0.89	8.00±4.06	0.84±0.48	72.30±23.48
		a	a	a	a
	Range	3.00-5.00	5.00-15.00	0.50- 1.50	50.00-118.00
Undisturbed forest	Mean	3.80±0.45	10.20±1.48	0.84±0.48	72.00±27.46
		ab	a	a	a
	Range	3.00-4.00	8.00-12.00	0.50-1.50	50.00-118.00
Landing bay	Mean	3.00±0.71	8.20±2.49	1.06±0.56	69.60±31.26
		b	a	a	a
	Range	2.00-4.00	6.00-12.00	0.50-2.00	30.00-117.00
Total	Mean	3.73±0.88	8.80±2.86	0.91±0.48	71.20±26.67
		2.00-5.00	5.00-15.00	0.50-2.00	30.00- 118.00
P-value		0.027	0.436	0.737	0.988

2.3 Effect of different forest soil disturbance types on percent survival of *Triplochiton scleroxylon* and *Terminalia superba* seedlings

Generally, in comparing the survival of *Terminalia superba* and *Triplochiton scleroxylon* seedlings under the different forest disturbance types, it was observed that the *Triplochiton scleroxylon* seedlings thrived better than the *Terminalia superba* seedlings. The percent survival of *Triplochiton scleroxylon* seedlings planted was 100% (i.e. all the seedlings under the different canopy types survived) and the survival percent of *Terminalia superba* seedlings recorded during the enrichment planting survival survey was 33% (Figure 2).

Comparison of soil bulk density under different forest soil disturbance types

The result showed significant differences ($p<0.05$) in soil bulk density across the different soil disturbance types. The skid trail soil bulk density was 1.51±0.19 g/cm^3, landing bay soil was 1.91±0.10 g/cm^3 and the control (undisturbed forest soil) was 1.20±0.18 g/cm3 (Figure 3).

Comparison of soil porosity under different forest soil disturbance types

Comparison of soil porosity under different soil disturbance types showed significant differences $p<0.05$. The undisturbed forest had the highest porosity of 58.65±7.18 % while the skid trail was 51.29±11.61%. The least soil porosity, 32.11±5.38 % was recorded at the landing bay forest soil disturbance area (Figure 4). The soil porosity of the skid trail soil significantly reduced by 12.5% compared to the control whereas the landing bay soil porosity significantly reduced by 45.3% compared to the control. Comparing the soil porosity between skid trail and landing bay soils were also significantly different by Fisher's LSD multiple comparison test.

Comparison of soil moisture content under different forest soil disturbance types

The soil moisture content recorded under the different canopy types were significantly different $p<0.05$. The skid trail forest showed the highest accumulation of soil moisture with an average of 13.20±3.27 m^3/m^3 followed by undisturbed forest with a mean of 13.16±2.63 (Figure 5). The least soil moisture content was 4.84±1.38 recorded in the landing bay forest soil. Fisher's LSD multiple comparison test showed significant difference ($p<0.05$) between the skid trail and the landing bay moisture content but there was no significant difference ($p>0.05$) in moisture contents between the skid trail and undisturbed forest soil.

Comparison of soil organic matter under different forest soil disturbance types

The undisturbed forest canopy provided the highest accumulation of organic matter with an average of 8.46±1.07 followed by skid trail forest canopy, 7.52±1.06. The least organic matter accumulation was recorded on the landing bay forest canopy

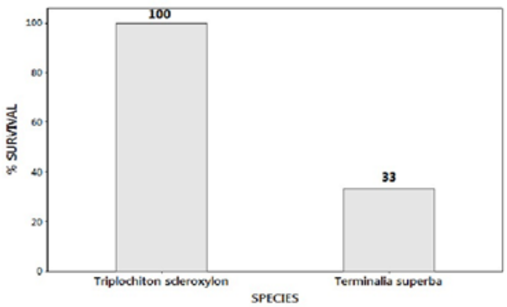

Figure 2. Survival of free seedlings planted on different soil disturbance and forest canopy gaps in Asamanyo Frorest reserve

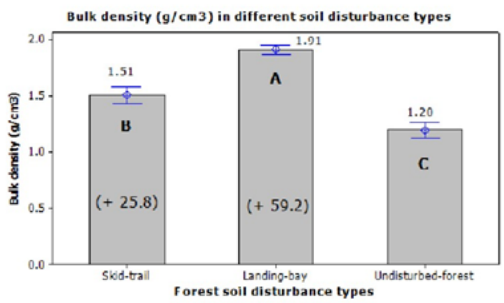

Figure 3. soil bulk density under different soil disturbance type in Asamanyo Frorest reserve

as 1.90±0.46 (Figure 6). The organic matter levels across the different canopy types were significantly different, p<0.05.

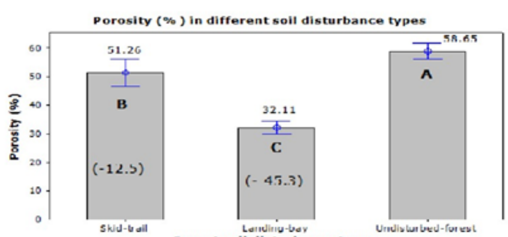

Figure 4. Soil porosity under different soil disturbance type in Asamanyo Frorest reserve

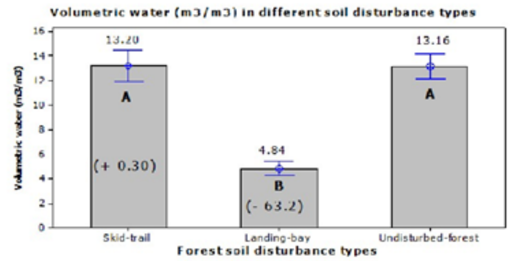

Figure 5. Soil moisture content under different soil disturbance type in Asamanyo Frorest reserve

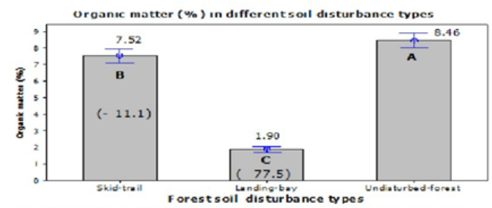

Figure 6. Soil organic matter content under different soil disturbance type in Asamanyo Frorest reserve

3. Discussion

The improved height growth performance of *Terminalia superba* in the undisturbed forest canopy than the landing bay and the skid trail forest canopy might be due to significant low soil bulk density in the undisturbed soil compared to soil in skid trail and landing bay soil. This findings support the assertion that soil displacement [17] and compaction probably, will have some undesirable effects on tree growth and soil organisms [16]. Reports also indicate a reduction in height growth of planted Douglas-fir after small percent increase in soil bulk density [17]. Percent change in soil bulk density is a reliable indicator of change in height growth and soil productivity[18]. The high mortality and poor seedling condition of *Terminalia superba* could be attributed to low light intensity in the undisturbed forest canopy compared to the landing bay and skid trail forest canopy. The better growth performance of *Triplochiton scleroxylon* in the undisturbed and skid trail forest canopy than the landing bay forest canopy observed during the survival survey of the enrichment planting could be due to differences in soil bulk density prevailing in the difference forest disturbance types. This finding confirms the assertion that soil displacement and compaction probably, will have some undesirable effects on tree growth [15]. Also the *Triplochiton scleroxylon* seedlings have the ability to grow well in high and low light intensity than *Terminalia superba* seedlings. This finding supports the contention that *Triplochiton scleroxylon* is a pioneer species and a light demander whereas *Terminalia superba* is a pioneer species and a strong light demander[19]. The soil bulk density of the skid trail was significantly increased by 25.8% compared to the control whereas the landing bay soil bulk density was significantly increased by 59.2%

compared to the control. The soil bulk density of the landing bay soil was also significantly higher ($p<0.05$) than the skid trail bulk density by Fisher's LSD multiple comparison tests. The increased in soil bulk density in the landing bay and skid trail soil compared to the control (undisturbed-forest) could be due to high pressure exerted by skidder traffic and logs in these areas. It has also found that after first pass of skidder (machinery) the amount of soil bulk density increase was 62% compared to control(undisturbed areas)[20]. Significant reduction in soil porosity of landing bay soil and skid trail soil compared to the control could be attributed to the significant rise in bulk density in these areas compared to the control. Bulk density is the measure of how water can infiltrate such that a significant increase in soil bulk density reduces the soil pore spaces which would cause infiltration problems for farmer's crops. This is in lined with the assertion that skidder traffic causes soil compaction in skid trail, reduced aeration and infiltration and causes run-off [21]. The soils under skid trail forest disturbance had the moisture content increased by 0.30% compared to the control whereas the landing bay soil had decreased soil moisture content by 63.2% compared to the control. The differences in soil moisture regime across the treatments could be due to high level of soil compaction in landing bay soil compared to control and skid trail soil. This finding supports the assertion that heavy equipment compact soil, reducing infiltration, rates and large-pore space for water movement [18][22]. The organic matter accumulation on the skid trail soil was significantly reduced by 11.1% compared to the control (undisturbed forest soil) but the landing bay organic matter content was significantly reduced by 77.5% compared to the control. Organic matter cohesion helps retention of soil fertility as the rate of leaching is reduced [23].

4. Conclusion

Generally, *Triplochiton scleroxylon* growth performance during the enrichment planting survival survey was better than the *Terminalia superba* .The survival percentage of *Terminalia superba* seedlings was 33%, whereas *Triplochiton scleroxylon* was 100%.The plant condition score at the end of the survival survey assessment across the different canopy types ranges from 0-5 for *Terminalia superba* and 2-5 for *Triplochiton scleroxylon* and the number of leaves across the areas for *Terminalia superba* ranges between 0-14 and *Triplochiton scleroxylon* number of leaves ranges between 5-15. Increased in soil bulk density influenced the growth performance of the planted seedlings. The soil bulk density of the skid trail was significantly increased by 25.8% compared to the control whereas the landing bay soil bulk density was significantly increased by 59.2% compared to the control. The *Triplochiton scleroxylon* seedlings did better in the enrichment planting than the *Terminalia superba* in all the soil disturbance types.

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References

[1] BLAY, D., APPIAH, M, DAMNYAG, L., DWOMOH, F.K, LUUKKANEN, O., and PAPPINEN, A. (2008). Involving Local Farmers in Rehabilitation of Degraded Forests: some lessons from Ghana. *Environ. Dev. Sustain.*, 10: 503-518

[2] APPIAH, M., BLAY, D., DAMNYAG, L., DWOMOH, F.K., PAPPINEN, A. and LUUKKANEN, O. (2009) Dependence on Forest Resources and Tropical Deforestation in Ghana. *Environ. Dev. Sustain.*, 11: 471-487

[3] FAO, (2010).Global Resources Assessment 2010.Country Report, Ghana.FRA 2010/077, Rome 2010

[4] MARFO, E. (2010). Chainsaw milling in Ghana: context, drivers and impacts. Tropenbos International, Wageningen, the Netherlands. Xii + pp. 64

[5] ODOOM, F.K. (2002). Hardwood Plantations in Ghana in Varmola, M. (ed.). *Forest Plantations Working Papers.* FAO Working Paper FP/24, Rome 2002

[6] D' OLIVEIRA, M.V.N. (2000). Artificial Regeneration in Gaps and Skidding trails alter Mechanised Forest Exploitation in Acre, Brazil. *Forest Ecology and Management*, 127(1): 67- 76

[7] KEEFE, K., SCHULZE, M.D., PINHEIRO, C., ZWEEDE, J.C., and ZARIN, D. (2009). Enrichment Planting as a Silvicultural Option in the Eastern Amazon: Case study of FazendaCauaxi. *Forest Ecology and Management*, 258: 1950-1959.

[8] ĂDJERS, G., HADENGGANAN, S., KUNSIPALO, J., NURYANTO, K., and VESA, L. (1995). Enrichment Planting of Dipterocarps in Logged-over Secondary Forests: effect of width, direction and maintenance method of planting line on selected Shorea species. *Forest Ecologyand Management*, 73:259-270

[9] APPIAH, M. (2003). Domestication of an Indigenous Tropical Forest Tree: silvicultural and socio-economic studies on Iroko (Milicia excelsa) in Ghana. PhD Thesis, Faculty of Agriculture and Forestry, University of Helsinki, Unioninkatu, pp. 104

[10] FAO, (1993). Timber Plantations in the Humid Tropics of Africa. *FAO Forestry Paper* 98, Rome 1993

[11] TAYLOR, C. J. (1960). Synecology and silviculture in Ghana. Thomas Nelson and Sons Ltd. Edinburgh, pp. 402

[12] CROSBIE, A.J. (1957). Soils of the Asenanyo Forest Reserve.Technical Report No. 19. Ghana Department of Soils and Land-use Survey.

[13] HALL, J.B., and SWAINE, M.D. (1981).Geobotany - Distribution and Ecology of Vascular Plants in a Tropical Rainforest Forest Vegetation in Ghana. *Dr. W. Junk Publishers*. The Hague pp. 382, 137

[14] ADDEY, J. and BARKER, N. (1995) Forest Management Units 37 (Asenanyo and Jimira Forest Reserve) Management Plan for the period: January 1996 to December 2015. Ghana Forestry Department, Planning Branch, Unpublished, Kumasi

[15] SMITH, R. B. andWASS, E. F. (1994). Impacts of skid roads on properties of a calcareous, loamy soil and on planted seedling performance. Can. For. Serv. Pac. For. Cent. Inf. Rep. BC – X – 346

[16] DICK, R.P., MYROLD, D. D. and KERLE, E. A. (1988). Microbial biomass and soil enzymes activities in compacted and rehabilitated skid trail soils, soil science society, *Am. J.* 52: 512 – 516

[17] FROEHLICH, H. A. (1979).The effect of compaction by logging on forest productivity.Final report contact 53500 – CT4 – 5(N). Bureau of Land Management, Portland, Oreg.

[18] FROECLICH, H. A. and MENABB, D. H. (1984).Minimizing soil compaction in Pacific Northwest forest.In forest soils and treatment impacts. Edited by E. L. Stone, University of Tennesse, Knoxville. Pp 159 – 192.

[19] ASARE, R. (2006). Learning about neighbor trees in cocoa growing systems: a manual for farmer trainers. Forest and Landscape Development and Environment series No. 4. 2006.

[20] WILLIAMSON, J., NEILSON, W. (2000). The influence of Forest site on rate and extent of soil compaction and profile disturbances of skid trails during ground-based harvesting: Canadian Journal Forest Research, 30:1196 – 1205 pp.

[21] HAMZA, M. A., and ANDERSON, W. K. (2005).Soil Compaction in cropping system. A review of the nature, causes and possible solutions. *Soil and Tillage Research.* 82 **(2)**: 121- 145.

[22] GREACEN, E.L. and SANDS, R. (1980). Compaction of forest soils: a review. *Aust. J. Soils Res.* 163 – 189.

[23] MONEY, H. A. (1972).The Carbon Balance of Planta. Ann. Rev. Ecol system: 3:314 – 46